Can shocks to risk aversion explain business cycle fluctuations in Bulgaria (1999-2019)?

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Abstract

Stochastic risk aversion is introduced into a dynamic general-equilibrium setup augmented with government. The theoretical framework is calibrated to Bulgarian data for the period 1999-2019. The quantitative relevance of shocks to risk aversion is investigated for the propagation of business cycles in the Bulgarian economy. More specifically, the presence of stochastic risk aversion in the theoretical setup improves the fit vis-à-vis data by increasing variability of employment and decreasing the variability of investment. However, those improvements are at the expense of lowering the variability of investment and wages in the model economy.

Keywords: business cycles, stochastic risk aversion, Bulgaria

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1 Introduction and Motivation

The classical real-business-cycle (RBC) model, e.g. Hansen (1985), revolutionized modern quantitative dynamic macroeconomics as it was a unique modelling tool that allowed researchers to construct artificial model economies, which resemble those of existing countries along important aggregate dimensions, and use those simulated environments to generate artificial, or model-predicted data, which is then compared to the properties of empirical (observed) data. In this way, all dynamic general-equilibrium frameworks could be regarded as disciplined data-generating mechanisms for data matching akin to the general method of moments (GMM) in econometrics. Alternatively, those simulated data series could be interpreted as a maximum likelihood estimation (MLE), investigating how likely it is that the observed time series were produced by the theoretical model. In addition, and in important contrast to ad hoc dynamic econometric models (e.g. - Vector-Auto-Regressions, or VARs) used in time series analysis, the important transmission mechanisms (based on inter- and intra-temporal optimality principles) in these theoretical model economies are explicit, as those setups are based on micro-foundations, so macroeconomists could gain a deeper understanding of the intricacies of the real economies. Finally, those model economies could be used as a laboratory, where different computational experiments can be safely executed, and which could produce quantitative insights about the expected and unexpected effects of policies and reforms that are still in a proposal stage.[1]

The general approach used in quantitative theoretical macroeconomic papers to set the values of the model parameters is referred to as *calibration*. In contrast to what many applied researchers wrongfully think or believe, calibration (when executed correctly) is not arbitrary at all; in particular, calibration is preferred to estimation in cases when (i) time series are too short to allow for a sensible estimation; (ii) when we already have data for certain parameters, like the depreciation rate, or the labour and capital shares; or (iii) we have a certain *target from data* that we need to match in the model, which will constrain the calibration procedure and determine (or *identify* in econometric language) the value of that parameter.[2] Finally, calibration is also preferred in cases when (iv) we do not have information on the parameter - when it is part of a characterization of an unobservable (latent) process, such as corruption - and want to investigate how the model predictions change when the parameter changes over a certain (plausible) range, i.e., how robust is the model to slight changes in certain parameters. Then, after calibrating all model parameters, we can proceed to simulate the model to produce artificial time series, and compare how the properties of simulated data change across the values of a particular parameter.

Regarding the variability of the parameters vs their means, the question: *Why settle for a particular point estimate?* is worth addressing, as by focusing exclusively on the average value, researchers are throwing up useful information.[3] Thus, holding the risk aversion parameter set to its mean over the course of the business cycle might lead to potentially incorrect conclusions, as those will be based on incomplete information. Therefore, in this paper we allow the risk aversion parameter to vary over time in order to evaluate the importance of the information contained in the variability of the risk parameter for business cycle fluctuations.[4] It is thus plausible to assume that a household's risk aversion can change over the business cycle. In the model setup, the risk aversion parameter shows up in the marginal rate of substitution for the household, which determines how consumption and labour supply decisions are made in each period, so a shock to the risk aversion parameter in turn will affect wages, interest rates, and thus production, investment, and capital accumulation decisions as well. Therefore, allowing for a stochastic risk aversion in the theoretical framework can produce additional interesting interactions among the aggregate variables in the model.

Following the argument above, this paper introduces a stochastic risk aversion parameter in a standard real-business-cycle (RBC) model with government. The model is calibrated for Bulgaria in the period 1999-2019, as Bulgaria provides a good testing case for the theory.[5] The paper proceeds to evaluate the effect of such a stochasticity as a possible alternative mechanism of business cycle propagation. This is the first study on the issue using modern macroeconomic modelling techniques, and thus an important contribution to studies on the country's economy. Unfortunately, for reasonable degree of risk aversion variability, the quantitative effects are tiny. In particular, allowing for a stochastic risk aversion in the setup improves the model fit vis-à-vis data by increasing variability of employment and decreasing the variability of investment. However, those improvements are at the expense of decreasing the volatility of investment and wages. The small effect of the risk aversion stochasticity can be viewed as a validation of the robustness of the standard RBC model.

The rest of the paper is structured as follows: Section 2 presents the model framework and defines the decentralized competitive equilibrium system, Section 3 presents the calibration procedure, and Section 4 discusses the steady-state model solution. Sections 5 proceeds with the study of the out-of-steady-state model dynamics, and evaluation of the model against data. Section 6 concludes the paper.

2 Model Description

There is a representative one-member household, which derives utility, and which features consumption and leisure as arguments. The total time endowment of the household can be spent in productive use or as leisure. The government taxes consumption and income to finance its purchases. Finally, on the production side, there is a stand-in firm, which rents labour and capital services to produce homogeneous final goods, which could be used for consumption, investment, or government purchases.

2.1 Household's problem

There is a typical one-member household, which maximizes the following expected utility function

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{c_t^{1-\sigma_t}}{1-\sigma_t} + \gamma \ln(1-h_t) \right\} \tag{1}$$

where E_0 operator reflects the household's expectations as of period 0, c_t is the household's private consumption in period t, h_t denotes hours worked in period t, $0 < \beta < 1$ is the discount factor, $0 < \gamma < 1$ is the relative utility weight attached to leisure, and $\sigma_t > 0$ is the time-varying risk aversion parameter.[6]

The household begins its life with an initial stock of physical capital $k_0 > 0$, and has to decide in each period thereafter how much to add to the capital stock via investment. The law of motion for physical capital is

$$k_{t+1} = i_t + (1-\delta)k_t, \tag{2}$$

where i_t is investment in period t, and $0 < \delta < 1$ is the depreciation rate. The real interest rate (before depreciation) is r_t, hence the before-tax capital income of the household in period t is $r_t k_t$. In addition to capital income, the household generates labour income: hours supplied to the stand-in firm are rewarded at the hourly wage rate of w_t, so pre-tax labour income is $w_t h_t$. Lastly, the household owns the firm in the economy and receives the firm's profit, π_t, as income.

Next, the household's problem is now to maximize (1) subject to

$$(1+\tau^c)c_t + k_{t+1} - (1-\delta)k_t = (1-\tau^y)[r_t k_t + \pi_t + w_t h_t] + g_t^t \tag{3}$$

where τ^c is the tax on consumption (VAT/sales tax), τ^y is the proportional income tax rate on both types of income ($0 < \tau^c, \tau^y < 1$), and g_t^t are government transfers, which are rebated lump-sum. The household takes the tax rates $\{\tau^c, \tau^y\}_{t=0}^{\infty}$, government transfers, $\{g_t^t\}_{t=0}^{\infty}$, profit $\{\pi_t\}_{t=0}^{\infty}$, the realized technology process $\{A_t\}_{t=0}^{\infty}$, the realized risk-aversion $\{\sigma_t\}_{t=0}^{\infty}$, and input prices $\{w_t, r_t\}_{t=0}^{\infty}$, and chooses $\{c_t, h_t, k_{t+1}\}_{t=0}^{\infty}$ to maximize its utility subject to the budget constraint.[7] The first-order optimality conditions are as follows:

$$c_t \ : \ E_t\left[\frac{1}{c_t^{\sigma_t}}\right] = \lambda_t(1+\tau^c) \tag{4}$$

$$h_t \ : \ \frac{\gamma}{1-h_t} = \lambda_t(1-\tau^y)w_t \tag{5}$$

$$k_{t+1} \ : \ \lambda_t = \beta E_t \lambda_{t+1}\Big[1 + [1-\tau^y]r_{t+1} - \delta\Big] \tag{6}$$

$$TVC \ : \ \lim_{t\to\infty} \beta^t \lambda_t k_{t+1} = 0 \tag{7}$$

where λ_t is the Lagrangian multiplier attached to the household's t-period budget constraint. The first-order conditions above are interpreted as follows: the first one states that the marginal utility of consumption of the household equals the marginal utility of wealth, corrected for the consumption tax rate; note that the presence of a stochastic risk aversion parameter will play an important role in this equation. The second optimality condition describes the equilibrium in the labour market: at the margin, each hour spent by the household working for the firm should balance the benefit from doing so in terms of additional income generated, and the cost measured in terms of lower utility of leisure. The third condition is the so-called "Euler equation," which describes the rule for capital allocation over time.

Again, there is a direct link between the shadow value λ and the stochastic risk aversion via the first optimality condition. The last condition, the "transversality condition" (TVC), is a boundary restriction, and is imposed to ensure stationarity: it states that at the end of the horizon, the value of physical capital should be zero in order to avoid explosive paths for capital.

2.2 Firm problem

There is a stand-in firm in the economy, which produces a homogeneous final product, with price normalized to unity. The production technology is assumed to be Cobb-Douglas and uses both physical capital, k_t, and labour hours, h_t, as inputs to maximize profit

$$\Pi_t = A_t k_t^{\alpha} h_t^{1-\alpha} - r_t k_t - w_t h_t, \tag{8}$$

where A_t is the level of total factor productivity (TFP) in period t. Since the firm rents the capital from households, the problem of the firm indeed collapses to a sequence of static profit maximizing problems. In equilibrium, there are no economic profits, $\pi_t = 0$, $\forall t$, and each input is priced according to its marginal product, i.e.,

$$k_t \ : \ \alpha \frac{y_t}{k_t} = r_t, \tag{9}$$

$$h_t \ : \ (1-\alpha) \frac{y_t}{h_t} = w_t. \tag{10}$$

2.3 Government

In the model in this paper, the government taxes all forms of income, as well as consumption, in order to finance spending on government purchases g_t^c, and government transfers. The government budget constraint is as follows:

$$g_t^c + g_t^t = \tau^c c_t + \tau^y [w_t h_t + r_t k_t + \pi_t] \tag{11}$$

Note that government transfers would be determined residually in each period to preserve the government budget in balance.[8]

2.4 Dynamic Competitive Equilibrium (DCE)

For the given processes followed by technology and risk aversion, $\{A_t, \sigma_t\}_{t=0}^{\infty}$, the tax schedules $\{\tau^c, \tau^y\}_{t=0}^{\infty}$, and the initial capital stock $\{k_0\}$, the decentralized dynamic competitive equilibrium is a list of sequences $\{c_t, i_t, k_t, h_t\}_{t=0}^{\infty}$ for the household, a sequence of government purchases and transfers $\{g_t^c, g_t^t\}_{t=0}^{\infty}$, and input prices $\{w_t, r_t\}_{t=0}^{\infty}$ such that (i) the representative household maximizes its utility function subject to its budget constraint; (ii) the stand-in firm maximizes profit; (iii) the government budget is always balanced; and (iv) all markets clear.

3 Data and Model Calibration

To characterize business cycle fluctuations in Bulgaria, we will focus on the period 1999-2019, which is after the introduction of the currency board arrangement, which brought macroeconomic stability. Quarterly data on the main aggregate variables: output, consumption and investment, was collected from the National Statistical Institute (2021), while the real interest rate is taken from the Bulgarian National Bank (2021). The calibration strategy followed in this paper is as follows: first, as in Vasilev (2020b), the discount factor, $\beta = 0.982$, is set to match the steady-state physical capital-to-output ratio in Bulgaria, $k/y = 13.964$, in the Euler equation. The risk parameter value in steady-state was set to $\sigma = 2$, which is a typical value in the literature.[9] Next, the labour share, $1 - \alpha = 0.571$, is obtained as in Vasilev (2017d), as the average value of labour income in aggregate output over the period 1999-2019. Next, the average income tax rate was set to its mean value in data, $\tau^y = 0.1$. Similarly, the average tax rate on consumption is set to its value over the period, $\tau^c = 0.2$.

Next, parameter γ is calibrated to match that in steady-state $h = 1/3$, which is in line with the estimates for Bulgaria (Vasilev 2017a) as well over the period studied. Next, the depreciation rate of physical capital in Bulgaria, $\delta = 0.013$, was estimated as in Vasilev (2016) as the average quarterly depreciation rate over the period 1999-2019. Finally, the Total factor productivity (TFP) process is estimated from the detrended Solow residuals series by running an AR(1) specification. Due to the lack of data, we use the same parameters for the risk aversion process. Table 1 contains all parameters values used in the paper.

Table 1: Model Parameters

Parameter	Value	Description	Method
β	0.982	Discount factor	Calibrated
σ	2.000	Risk aversion	Set
α	0.429	Capital Share	Data average
$1-\alpha$	0.571	Labour Share	Calibrated
γ	0.873	Relative weight on leisure	Calibrated
δ	0.013	Depreciation rate, physical capital	Data average
τ^y	0.100	Average tax rate on income	Data average
τ^c	0.200	VAT/consumption tax rate	Data average
ρ_a	0.701	AR(1) persistence coefficient, TFP process	Estimated
σ_a	0.044	st. error, TFP process	Estimated
ρ_s	0.701	AR(1) persistence coefficient, risk aversion	Set
σ_s	0.044	st. error, risk aversion	Set

4 Steady-State

Once the model has been parameterized, and the equilibrium system has been solved for the steady-state, the "big ratios" predicted by the model can be compared to their empirical averages in Bulgarian data, with the results reported in Table 2 below. The steady-state level of output was normalized to unity, which allowed for an analytical solution. Interestingly, the stochastic risk aversion plays no role in the steady-state computation. Overall, the model matches consumption-to-output and government purchases ratios by construction; the investment ratio is also closely approximated. Next, the shares of income are also identical to those in data, which is an artifact of the assumptions imposed on the functional form of the aggregate production function. Finally, the after-tax return, where $\bar{r} = (1-\tau^y)r - \delta$, is also relatively well-captured by the model.

Table 2: Data Averages and Long-run Solution

Variable	Description	Data	Model
y	Steady-state output	N/A	1.000
c/y	Consumption-to-output ratio	0.648	0.674
i/y	Investment-to-output ratio	0.201	0.175
k/y	Capital-to-output ratio	13.96	13.96
g^c/y	Government consumption-to-output ratio	0.151	0.151
wh/y	Labour income-to-output ratio	0.571	0.571
rk/y	Capital income-to-output ratio	0.429	0.429
h	Share of time spent working	0.333	0.333
$\bar{r}$	After-tax net return on capital	0.014	0.016

5 Out of steady-state model dynamics

Since the model does not yield an analytical solution outside the steady-state, we solve it numerically, by log-linearizing the original equilibrium system. This transformation produces a system of stochastic linear difference equations. First, we study the dynamic behaviour of model variables in response to an isolated shock to the total factor productivity-, and the risk aversion process, and then we proceed to fully simulate the model in order to compare how the model performs when compared against data.

5.1 Impulse Response Analysis

This subsection presents the impulse response functions (IRFs) of model variables to a 1% surprise innovation to technology and the risk aversion shocks, in Fig. 1 and 2, respectively. As a result of the technology shock, output increases upon impact, which also expands the availability of resources in the economy; thus, uses of output – consumption, investment, and government consumption also increase contemporaneously.

At the same time, the increase in total factor productivity increases the after-tax returns on both factors of production, labour and capital. The representative household optimally responds to the incentives, and invests more, and works more. In turn, the increase in capital stock further increases output through the production function. Similarly, the increase in total hours further increases output, again indirectly.

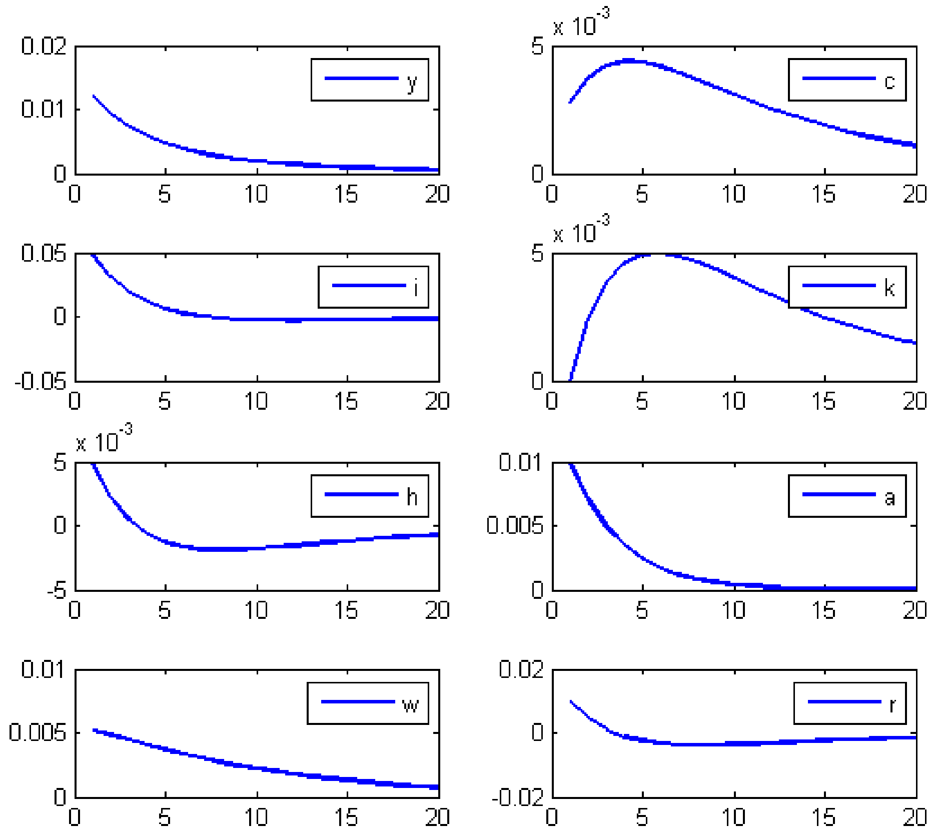

Figure 1: Impulse Responses to a 1% surprise innovation in technology

Over time, as physical capital is being accumulated, its after-tax marginal product starts to decline, which lowers the households' incentives to save; physical capital stock eventually returns to its steady-state, and exhibits a hump-shaped dynamics over its transition path. The rest of the model variables (aside from consumption) return to their old steady-states in a monotone fashion.

Next, the quantitative effect of the shock to the risk aversion parameter , presented in Fig. 2, is quite small, so changes in risk aversion are unlikely candidates for business cycle propagators. In particular, upon impact of the shock, the marginal utility of consumption (the shadow price) decreases, which is why we see that consumption has increased. Investment decreases, and capital accumulation drops. Next, from the marginal rate of substitution equation, it follows that hours worked have to increase, which simultaneously decreases the wage rate. The increase in hours worked increases directly output, and indirectly the marginal productivity of capital, due to the complementarity between labour and capital in the Cobb-Douglas production function; in turn, the interest rate increases. We see this in the Euler equation, which is disturbed, as the shadow prices in both period t and $t+1$ are disturbed. To preserve the balance, the interest rate in period $t+1$ needs to increase; this is because now the consumer values consumption today more relative to consumption tomorrow, which discourages investment, and thus capital stock decreases relative to its steady state. Overall, the effect of the shock to risk aversion is very short-lived, and variables return quickly to their old steady-states.

5.2 Simulation and moment-matching

As in Vasilev (2017b), we proceed to simulate the model; both empirical and model simulated data is detrended the same way - using the Hodrick-Prescott (1980) filter. Table 3 on the next page summarizes the results. The cases considered are the setups with both shocks at work, as well as with risk aversion-, and technology shocks only, respectively. As in Vasilev (2016, 2017b, 2017c), all setups match quite well the absolute volatility of output and investment. In addition, by construction, government consumption in the models varies as much as output. In the model with both shocks, the predicted consumption and investment volatilies are too high. Still, the model is qualitatively consistent with the stylized fact for Bulgaria that consumption is smoother than output, while investment is much more volatile. In addition, the model with both shocks produces more volatile consumption and employment, and smoother investment series, relative to a setup with technology shocks alone, but the quantitative effect is rather small. Overall, the two models are almost indistinguishable from one another. The model with only shocks to risk aversion is a particularly bad fit, thus risk shocks are an unlikely candidate to cause the observed business cycles in Bulgaria.

Along the labour market dimension, the variability of employment and wages predicted by the model with both shocks is lower than that in data. Next, the model systematically

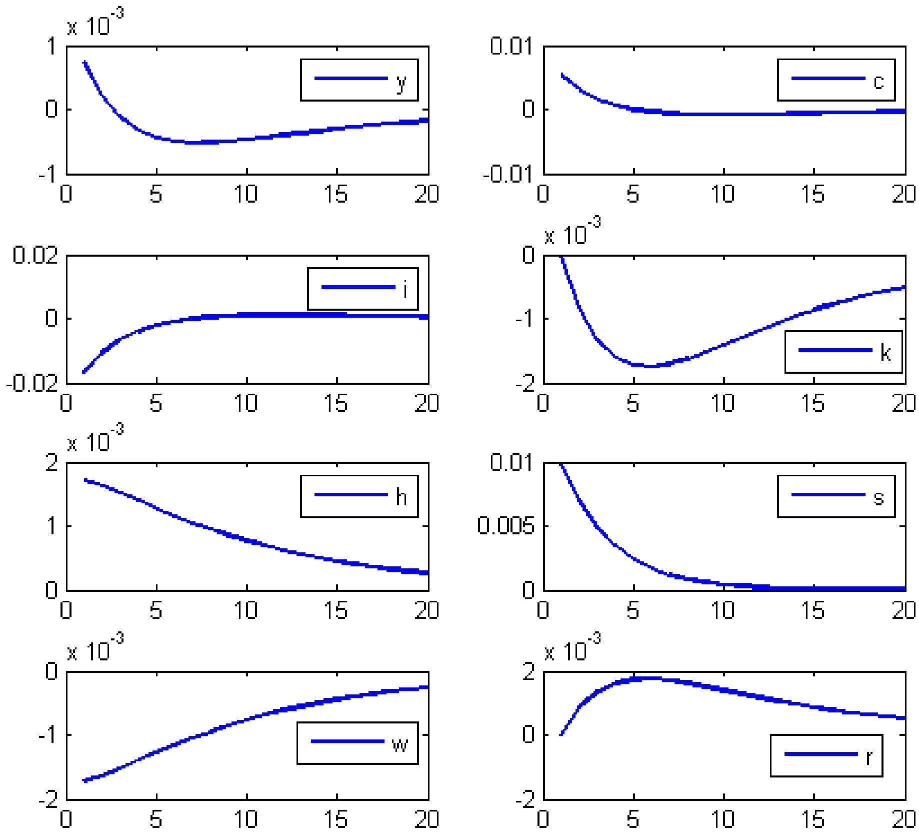

Figure 2: Impulse Responses to a 1% surprise innovation in technology (flat capital tax case)

over-predicts the pro-cyclicality of the main aggregate variables - consumption, investment, and government consumption. All those are common limitations of this class of models. In addition, the contemporaneous correlation of employment with output is too low; furthermore, the model predicts strong cyclicality, while wages in data are acyclical. This is another shortcoming in the literature, which is well known, and due to the wage being equal to the labour productivity in the model.

We proceed to discuss the auto-correlation functions (ACFs) of the major model variables. The coefficients of the empirical ACFs are presented in Table 4 against the averaged simulated AFCs. For the sake of brevity, we only present the results from the setup with both shocks.

Table 3: Business Cycle Moments

	Data	Both Shocks	Risk shocks only	Technology Shocks only
σ_y	0.05	0.05	0.05	0.05
σ_c/σ_y	0.55	0.89	2.24	0.82
σ_i/σ_y	1.77	2.32	7.74	2.35
σ_g/σ_y	1.21	1.00	1.00	1.00
σ_h/σ_y	0.63	0.44	2.59	0.28
σ_w/σ_y	0.83	0.78	2.59	0.86
$\sigma_{y/h}/\sigma_y$	0.86	0.78	2.59	0.86
$corr(c, y)$	0.85	0.87	0.46	0.90
$corr(i, y)$	0.61	0.74	0.08	0.83
$corr(g, y)$	0.31	1.00	1.00	1.00
$corr(h, y)$	0.49	0.33	0.79	0.59
$corr(w, y)$	-0.01	0.92	0.79	0.96

Table 4: Autocorrelations for Bulgarian data and the model economy

		k			
Method	Statistic	0	1	2	3
Data	$corr(n_t, n_{t-k})$	1.000	0.484	0.009	0.352
Model	$corr(n_t, n_{t-k})$	1.000	0.956	0.904	0.843
	(s.e.)	(0.000)	(0.027)	(0.052)	(0.075)
Data	$corr(y_t, y_{t-k})$	1.000	0.810	0.663	0.479
Model	$corr(y_t, y_{t-k})$	1.000	0.957	0.903	0.843
	(s.e.)	(0.000)	(0.025)	(0.049)	(0.071)
Data	$corr(a_t, a_{t-k})$	1.000	0.702	0.449	0.277
Model	$corr(a_t, a_{t-k})$	1.000	0.955	0.901	0.837
	(s.e.)	(0.000)	(0.027)	(0.053)	(0.077)
Data	$corr(c_t, c_{t-k})$	1.000	0.971	0.952	0.913
Model	$corr(c_t, c_{t-k})$	1.000	0.958	0.908	0.851
	(s.e.)	(0.000)	(0.025)	(0.040)	(0.070)
Data	$corr(i_t, i_{t-k})$	1.000	0.810	0.722	0.594
Model	$corr(i_t, i_{t-k})$	1.000	0.953	0.895	0.827
	(s.e.)	(0.000)	(0.029)	(0.055)	(0.080)
Data	$corr(w_t, w_{t-k})$	1.000	0.760	0.783	0.554
Model	$corr(w_t, w_{t-k})$	1.000	0.959	0.909	0.853
	(s.e.)	(0.000)	(0.024)	(0.047)	(0.069)

As seen from Table 4 above, the model compares relatively well against data, even though the empirical ACFs for output and investment are slightly outside the confidence band predicted by the model; still, the ACFs for total factor productivity and household consumption are well-approximated by the model. The persistence of labour market variables are also relatively well-captured by the model dynamics. Overall, the model with both technological shocks and stochastic risk aversion is way too persistent. Next, as seen from Table 5, over the business cycle, in data, employment follows labour productivity. The current model, however, cannot capture this dynamic relationship, as in the setup, the technology shock shifts the labour demand curve, while holding the labour supply curve constant, thus producing only a contemporaneous correlation.

Table 5: Dynamic correlations for Bulgarian data and the model economy

		k						
Method	Statistic	-3	-2	-1	0	1	2	3
Data	$corr(h_t, (y/h)_{t-k})$	-0.342	-0.363	-0.187	-0.144	0.475	0.470	0.346
Model	$corr(h_t, (y/h)_{t-k})$	-0.01	-0.024	-0.042	-0.620	-0.400	-0.359	-0.316
	(s.e.)	(0.342)	(0.299)	(0.247)	(0.307)	(0.278)	(0.308)	(0.341)
Data	$corr(h_t, w_{t-k})$	0.355	0.452	0.447	0.328	-0.040	-0.390	-0.57
Model	$corr(h_t, w_{t-k})$	-0.01	-0.024	-0.042	-0.620	-0.400	-0.359	-0.316
	(s.e.)	(0.342)	(0.299)	(0.247)	(0.307)	(0.278)	(0.308)	(0.341)

6 Conclusions

Stochastic risk aversion is introduced into a dynamic general-equilibrium setup augmented with government. The theoretical framework is calibrated to Bulgarian data for the period 1999-2019. The quantitative relevance of shocks to risk aversion is investigated for the propagation of business cycles in the Bulgarian economy. More specifically, the presence of stochastic risk aversion in the theoretical setup improves the fit vis-à-vis data by increasing variability of employment and decreasing the variability of investment. However, those improvements are at the expense of lowering the variability of investment and wages in the model economy. Thus, shocks to risk aversion in this context are not a likely candidate for a quantitatively important driving force behind business cycle fluctuations.

Notes

[1]This is again a strong advantage to econometric estimation, which is not useful in such situations.

[2]This is the case with the weight on utility of leisure.

[3]As pointed out in Vasilev (2020a), an alternative approach in macroeconomic modelling is to estimate RBC models using Bayesian techniques, where each parameter is taken from a distribution.

[4]Parkin (1988) uses such a technique to study whether RBC model parameters are "structural." Similarly, for Bulgaria Vasilev (2020a) investigates the relevance of having a stochastic capital share; Vasilev (2019a)

addresses the effect of a stochastic leisure preference parameter in a standard RBC framework, while Vasilev (2019b) focuses on the quantitative effect of an endogenously determined depreciation rate in an RBC setup.

[5]Bulgaria is a former transition economy, and despite the EU membership, it is still developing; The results could be thus relevant for other developing economies.

[6]Note that the last parameter is also the inverse of the intertemporal elasticity of substitution between consumption in period t, and consumption in period $t+1$.

[7]Note that by choosing k_{t+1} the household indirectly determines investment i_t optimally as well. That is why i_t was excluded from the list above, as there is no separate decision made about it.

[8]This assumption is not crucial in any way. Since we are abstracting from debt, which is quite low in Bulgaria, we need transfers to adjust to make the equation balance.

[9]Experimenting with a wider range of values, *i.e.*, $\sigma \in [1, 3]$ did not affect the results from the paper in any major way.

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